Our place in the Universe

Viz: Stuart Levy, Bob Patterson, Donna Cox (NCSA), Data: Hipparcos, Brent Tully, and other sources

Today

Tom Abel
KIPAC

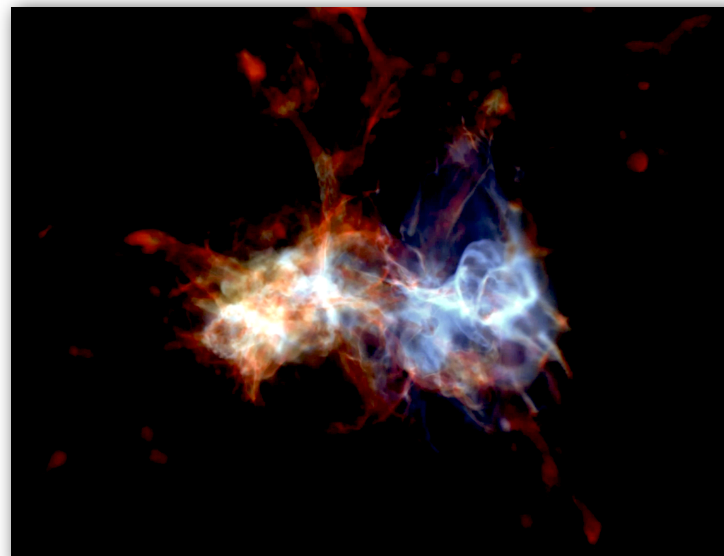
The Birth, Life & Aftermath of the First Stars

Tom Abel
KIPAC/Stanford

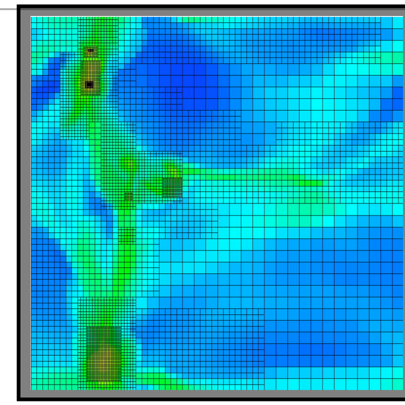
work with

Matt Turk (Birth)
John Wise (Life)

Ralf Kähler (Scientific Visualization)



Outline

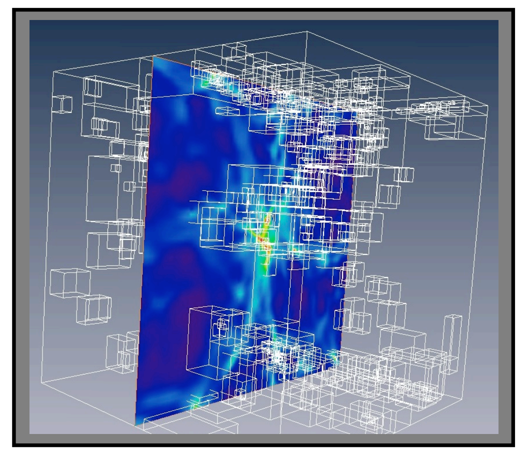


- Conception

- A difficult birth

- A surprising life

- Remarkable consequences

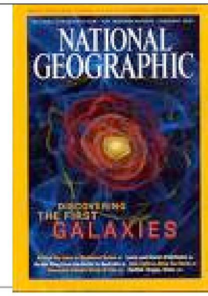


- Three-D radiation transport around point sources

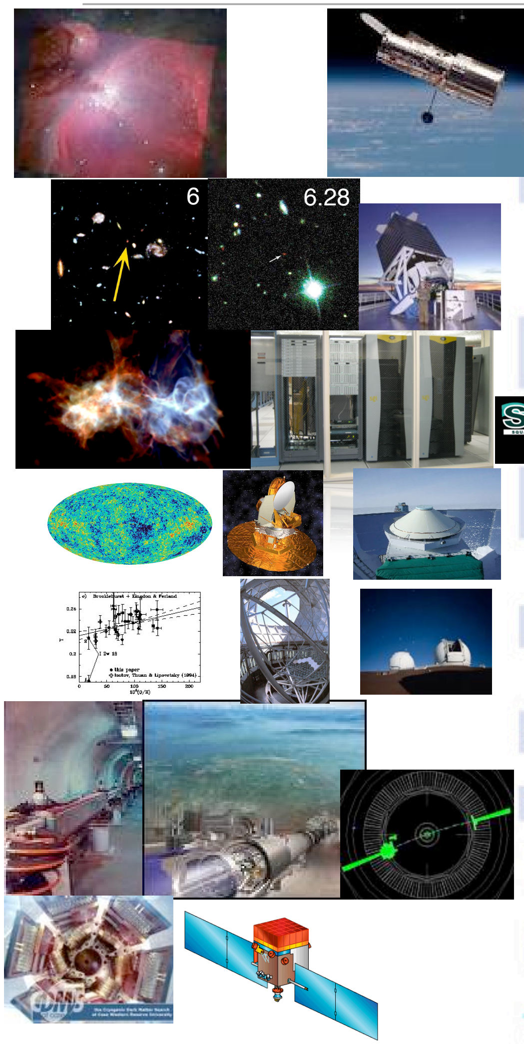
- Spatially & temporally structured adaptive cosmological & relativistic hydrodynamics

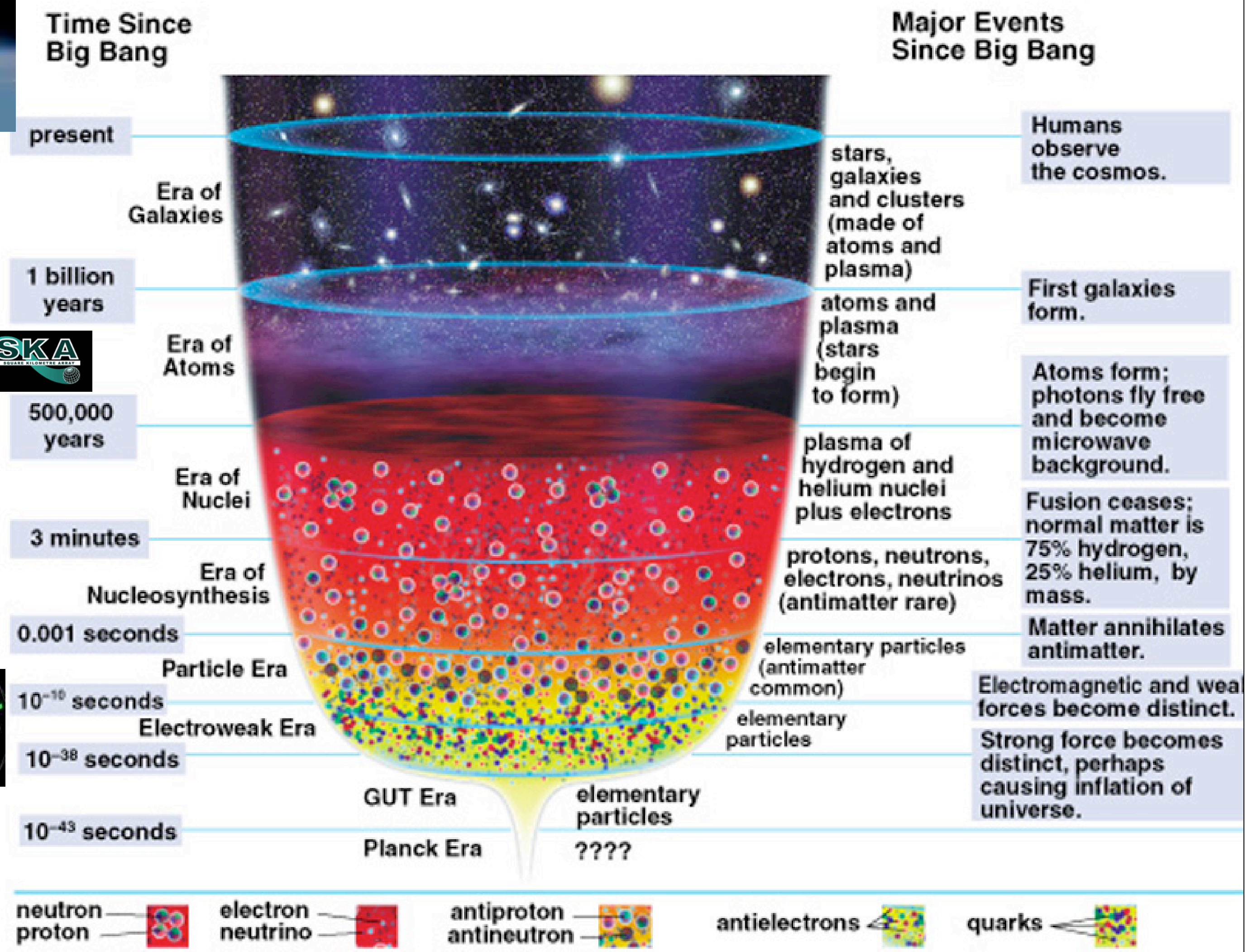
- public version of enzo at: http://lca.ucsd.edu/portal/software/enzo

How we find things:



Discovery by Computer?

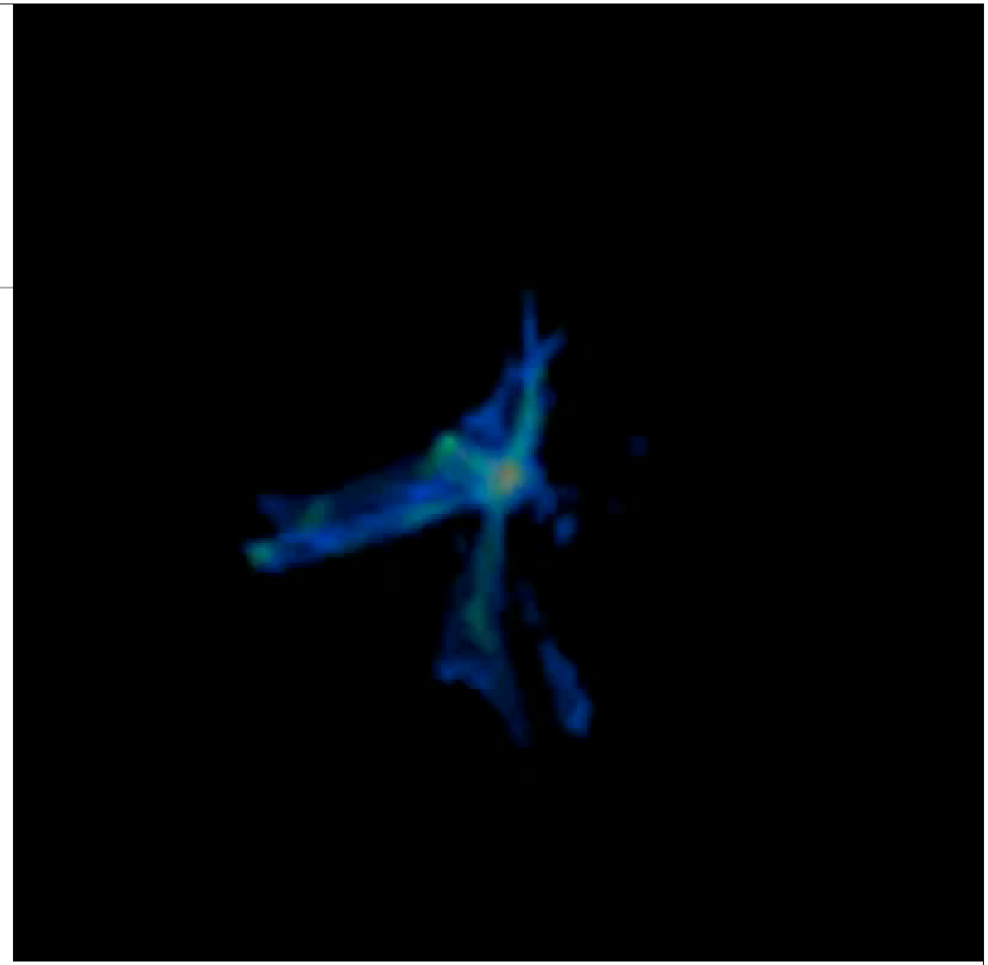




Conception

Physics problem:

- Initial Conditions: COBE/ACBAR/Boomerang/WMAP/CfA/SDDS/2DF/CDMS/DAMA/Edelweiss/... + Theory: Constituents, Density Fluctuations, Thermal History
- Physics: Gravity, MHD, Chemistry, Radiative Cooling, Radiation Transport, Cosmic Rays, Dust drift & cooling, Supernovae, Stellar evolution, etc.
- Transition from Linear to Non-Linear:
- Using patched based structured adaptive (space & time) mesh refinement

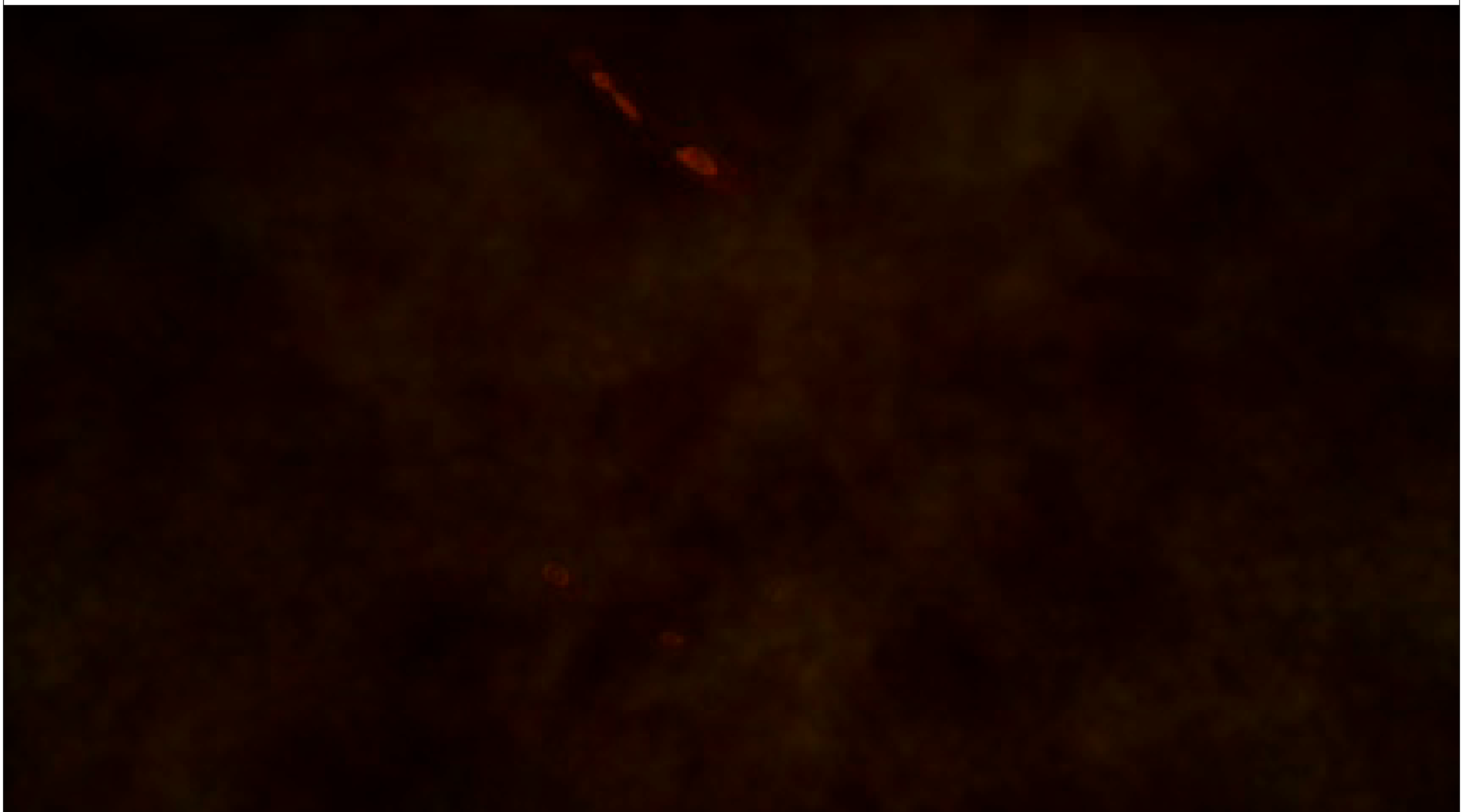


Ralf Kähler & Tom Abel for PBS Origins. Aired Dec 04

$$\frac{R_\odot}{R_{\rm Milky Way}} \approx 10^{-12}$$

$$\frac{P_{\odot,\rm Kepler}}{t_{\rm Hubble}(z=30)} \approx 10^{-12}$$

Making a proto-star

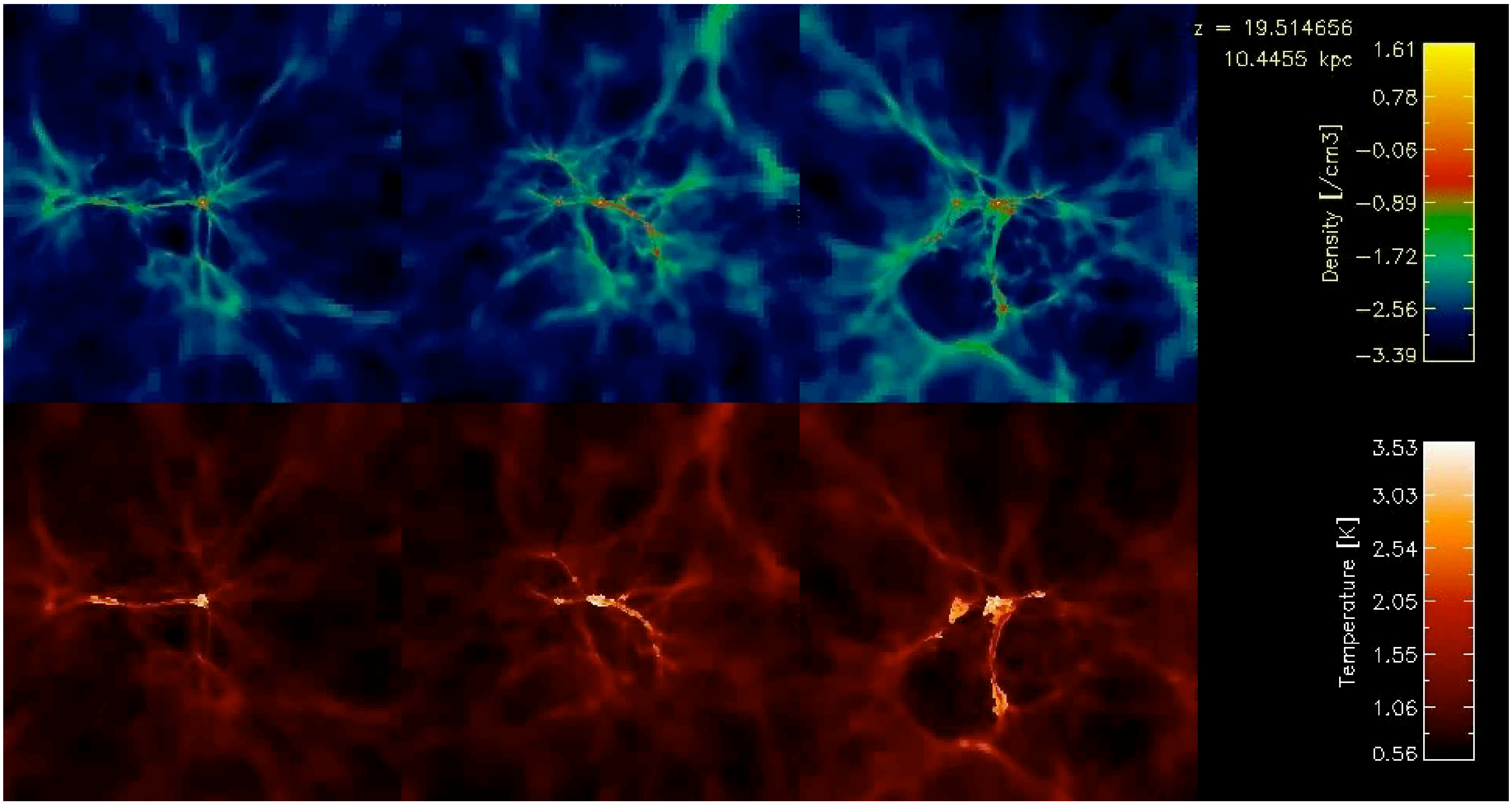


Simulation: Tom Abel (KIPAC/Stanford), Greg Bryan (Columbia), Mike Norman (UCSD)
Viz: Ralf Kähler (AEI, ZIB, KIPAC), Bob Patterson, Stuart Levy, Donna Cox (NCSA), Tom Abel

Zoom in

Dynamic range ~1e12.
> 30 levels of refinement
tens of thousands of grid patches
dynamically load balanced
MPI. 16 processors enough

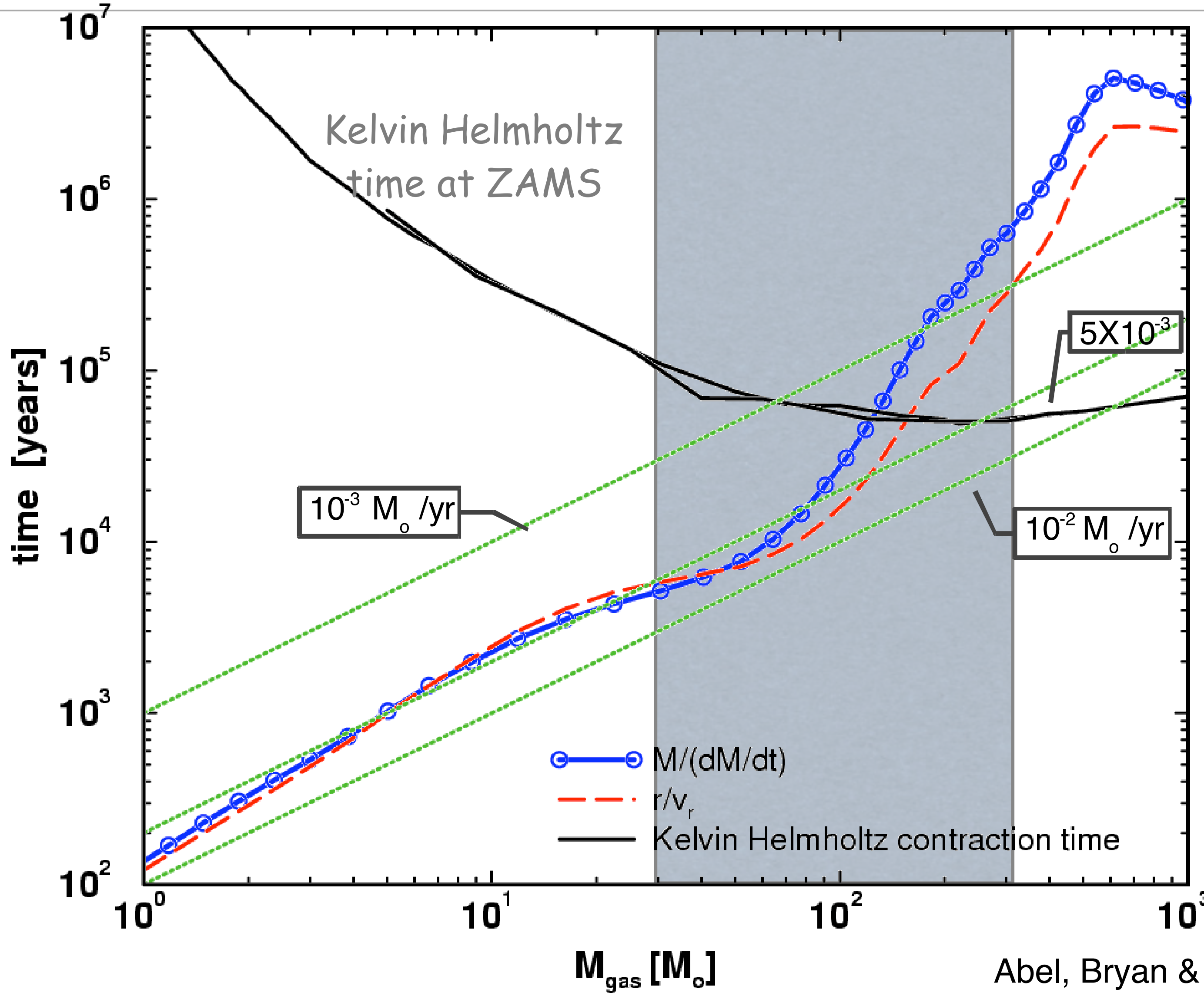
Typically 3 solar mass dm particles
> 8 cells per local Jeans Length
non-equilibrium chemistry
RT effects above 1e12 cm^{-3}



Note disks within disks happen routinely in turbulent collapses!

Turk & Abel in prep

Mass Scales?



Abel, Bryan & Norman 2002

Recap

First Stars are isolated and very massive

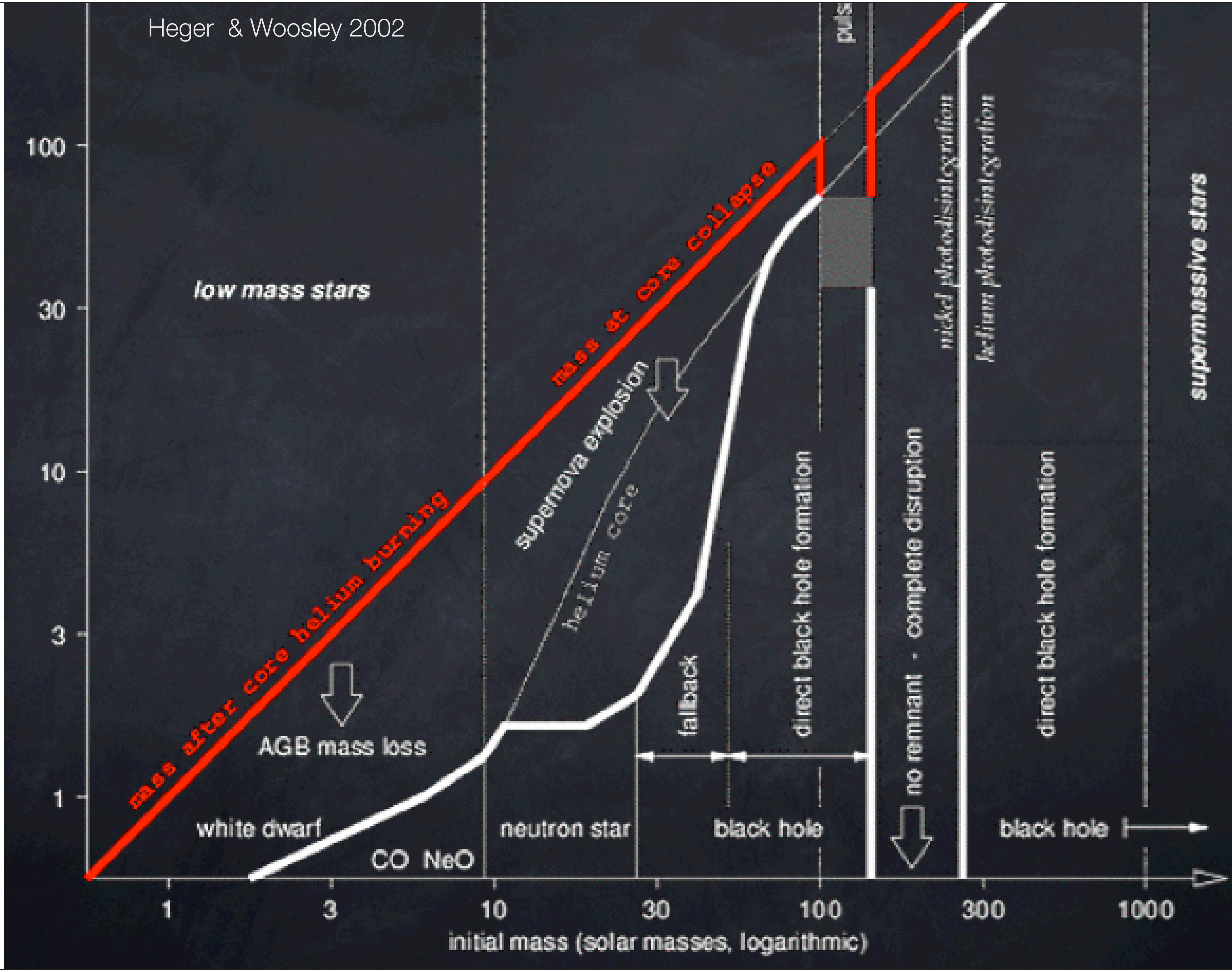
- Theoretical uncertainty: 30 - 300 solar mass

  Many simulations with three different numerical techniques and a large range of numerical resolutions have converged to this result. Some of these calculations capture 20 orders of magnitude in density!

  Non-equilibrium chemistry & cooling, three body H2 formation, chemical heating, H2 line transfer, collision induced emission and its transport, and sufficient resolution to capture chemo-thermal and gravitational instabilities.
  Stable results against variations on all so far test dark matter variations, as well as strong soft UV backgrounds.

- Perfectly consistent with observation!
  Could have been a real problem!

cosmological: Abel et al 1998; Abel, Bryan & Norman 2000, 2002; O'Shea et al 2006; Yoshida et al 2006; Gao et al 2006
idealized spheres: Haiman et al 1997; Nishi & Susa 1998; Bromm et al 1999,2000,2002; Ripamonti & Abel 2004



Heger & Woosley 2002
low mass stars
mass after core helium burning
mass at core collapse
supernova explosion
helium core
AGB mass loss
white dwarf
CO NeO
neutron star
fallback
black hole
direct black hole formation
puls
no remnant - complete disruption
nickel photodisintegration
helium photodisintegration
direct black hole formation
black hole
supermassive stars
100
30
10
3
1
1
3
10
30
100
300
1000
initial mass (solar masses, logarithmic)

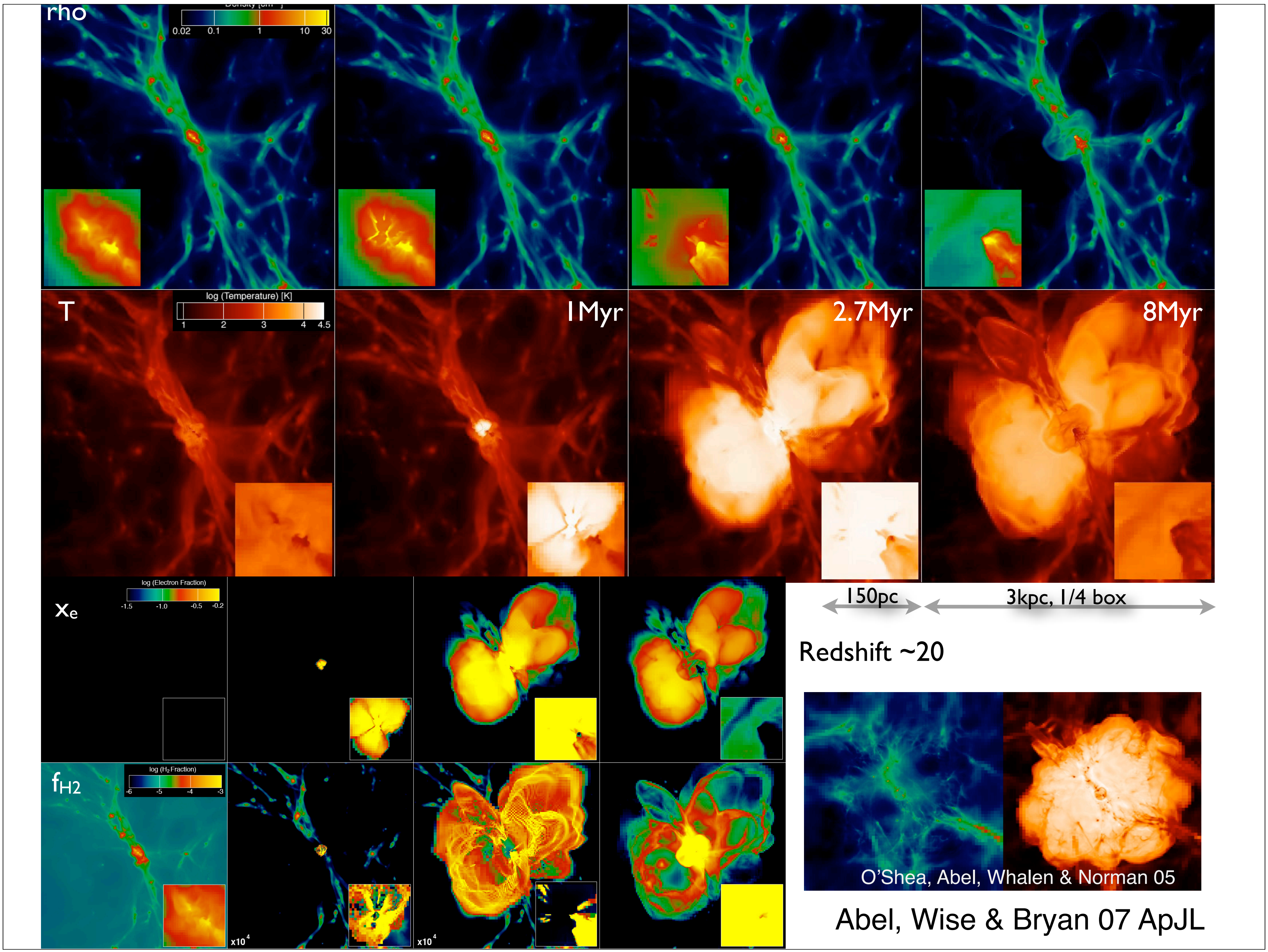
Violent Death

- Supernovae
  - Type II
  - Pair-instability
- Gamma Ray Bursts
  - Neutrino driven?
  - B field driven?
- Direct Black Hole Formation

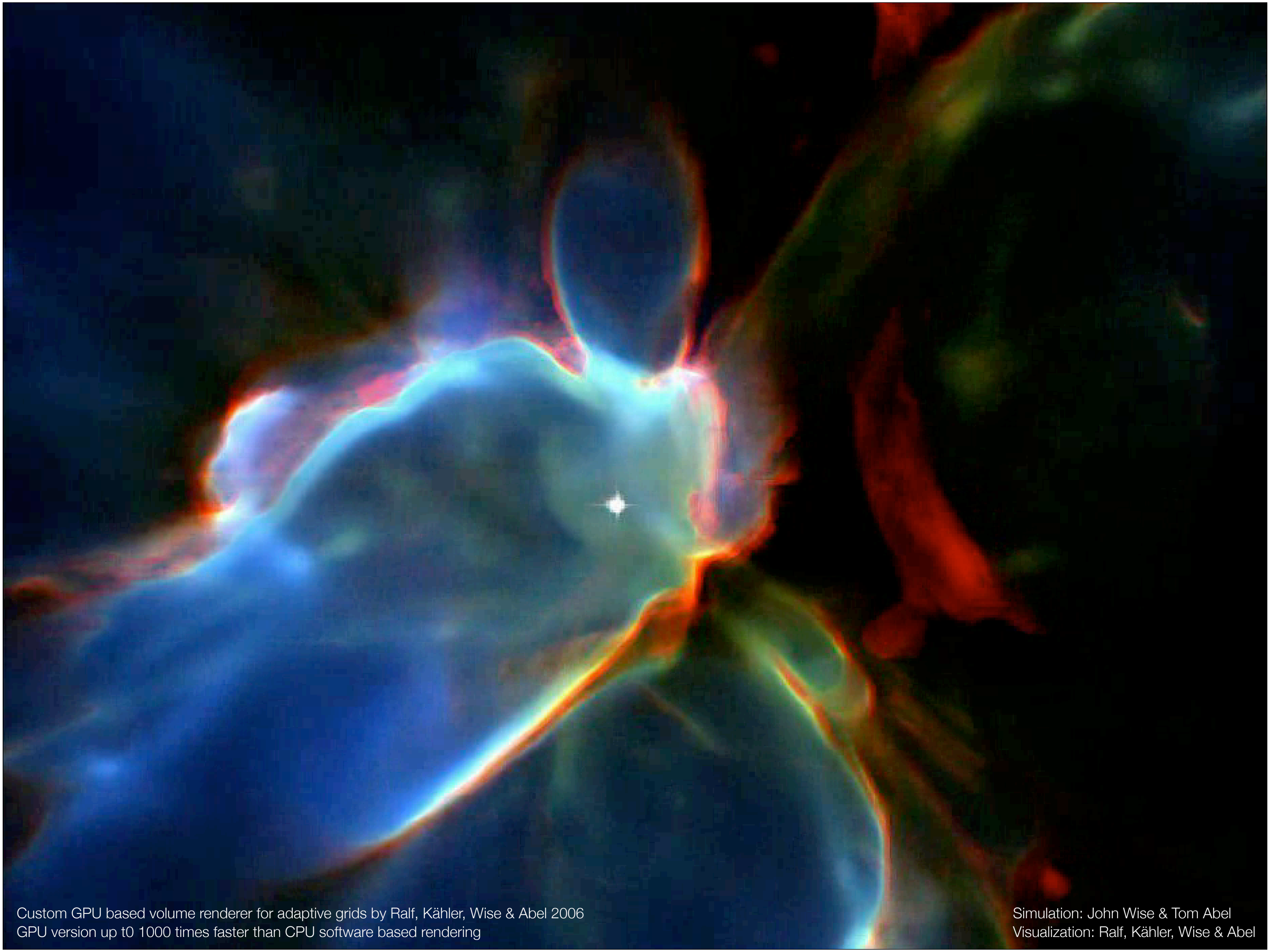
Tumultuous Life

- Entire mass range are strong UV emitters
- Live fast, die young. (2.7 Myr)
- Fragile Environment
  - Globular Cluster mass halo but ~100 times as large -> small v_{esc} ~ 2 km/s
  - Birth clouds are evaporated


CALIFORNIA NEBULA, NGC1499
500 pc = 1,500 light years away
30 pc long
Xi Persei, منكب mankib, Shoulder of Pleiades:
O7.5III
330,000 solar luminosities
~40 solar masses, Teff=3.7e4K

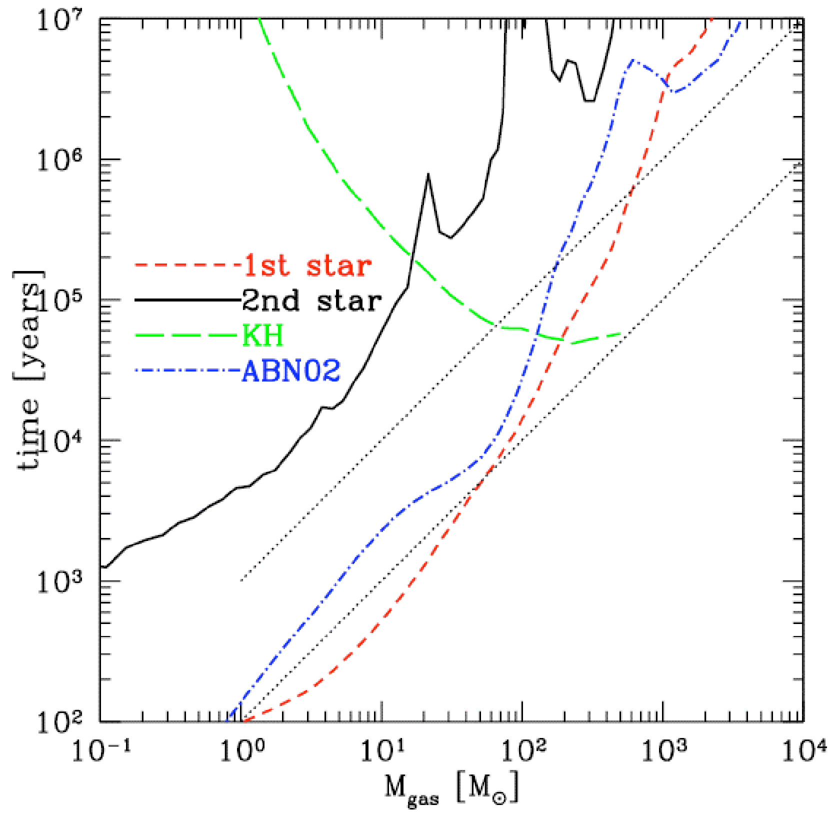


rho
0.02 0.1 1 10 30
T
log (Temperature) [K]
1 2 3 4 4.5
1Myr
2.7Myr
8Myr
xe
log (Electron Fraction)
-1.5 -1.0 -0.5 -0.2
fH2
log (H2 Fraction)
-6 -5 -4 -3
x10^4
x10^4
150pc
3kpc, 1/4 box
Redshift ~20
O'Shea, Abel, Whalen & Norman 05
Abel, Wise & Bryan 07 ApJL


Custom GPU based volume renderer for adaptive grids by Ralf, Kähler, Wise & Abel 2006
GPU version up t0 1000 times faster than CPU software based rendering
Simulation: John Wise & Tom Abel
Visualization: Ralf, Kähler, Wise & Abel

Feedback changes ICs and stellar masses.

- Input on small scales ...
- Formation of disks more common?
- Caveat: Small numbers of simulations so far
- Mass range: 10-100 in second generation of metal free stars? This second generation may be much more abundant.



O'Shea, Abel, Whalen & Norman 2005
Yoshida et al 2006

3D Cosmological Radiation Hydrodynamics

Focus on point sources

Early methods: Abel, Norman & Madau 1999 ApJ; Abel & Wandelt 2002, MNRAS; Variable Eddington tensors: Gnedin & Abel 2001, NewA

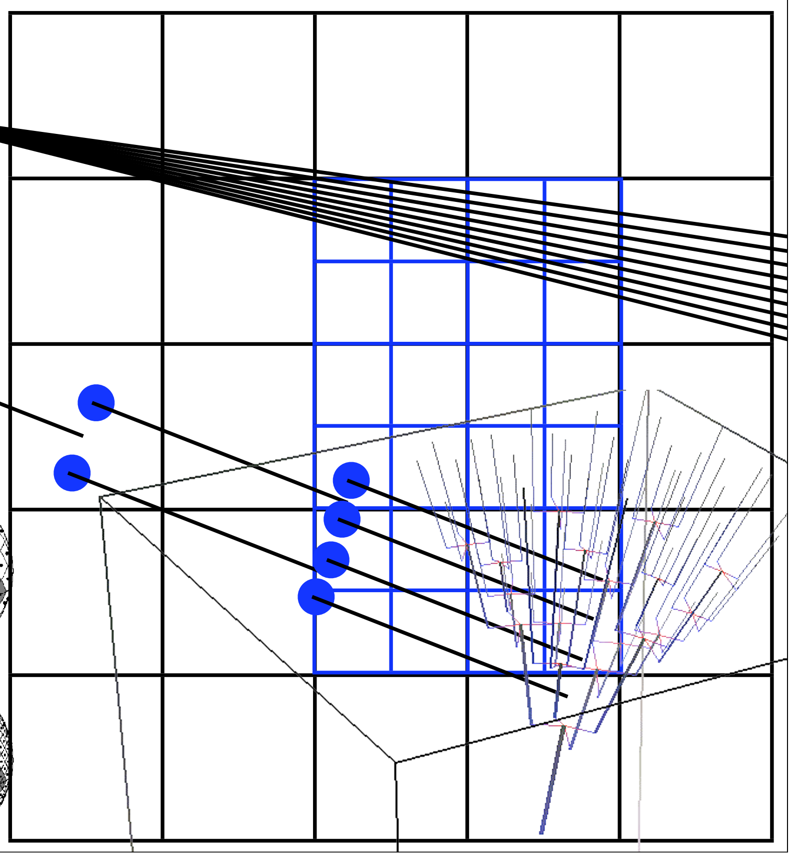
Latest: Abel, Wise & Bryan 06 astro-ph/0606019. Keeps time dependence of transfer equation using photon package concept from Monte Carlo techniques, yet not using any random numbers.

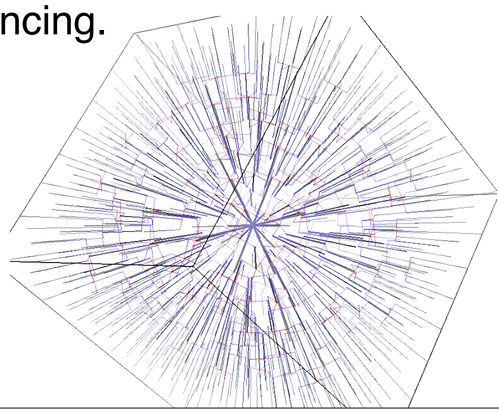
Adaptive ray-tracing of PhotonPackages using HEALPIX pixelization of the sphere. Photon conserving at any resolution.

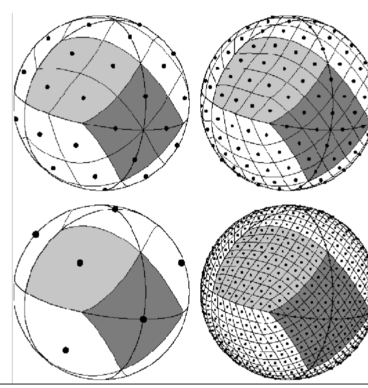
Parallel using MPI and dynamic load balancing.

$$\frac{1}{c}\frac{\partial I_\nu}{\partial t} + \frac{\partial I_\nu}{\partial r} = -\kappa I_\nu$$

Transfer done along adaptive rays
Case B recombination



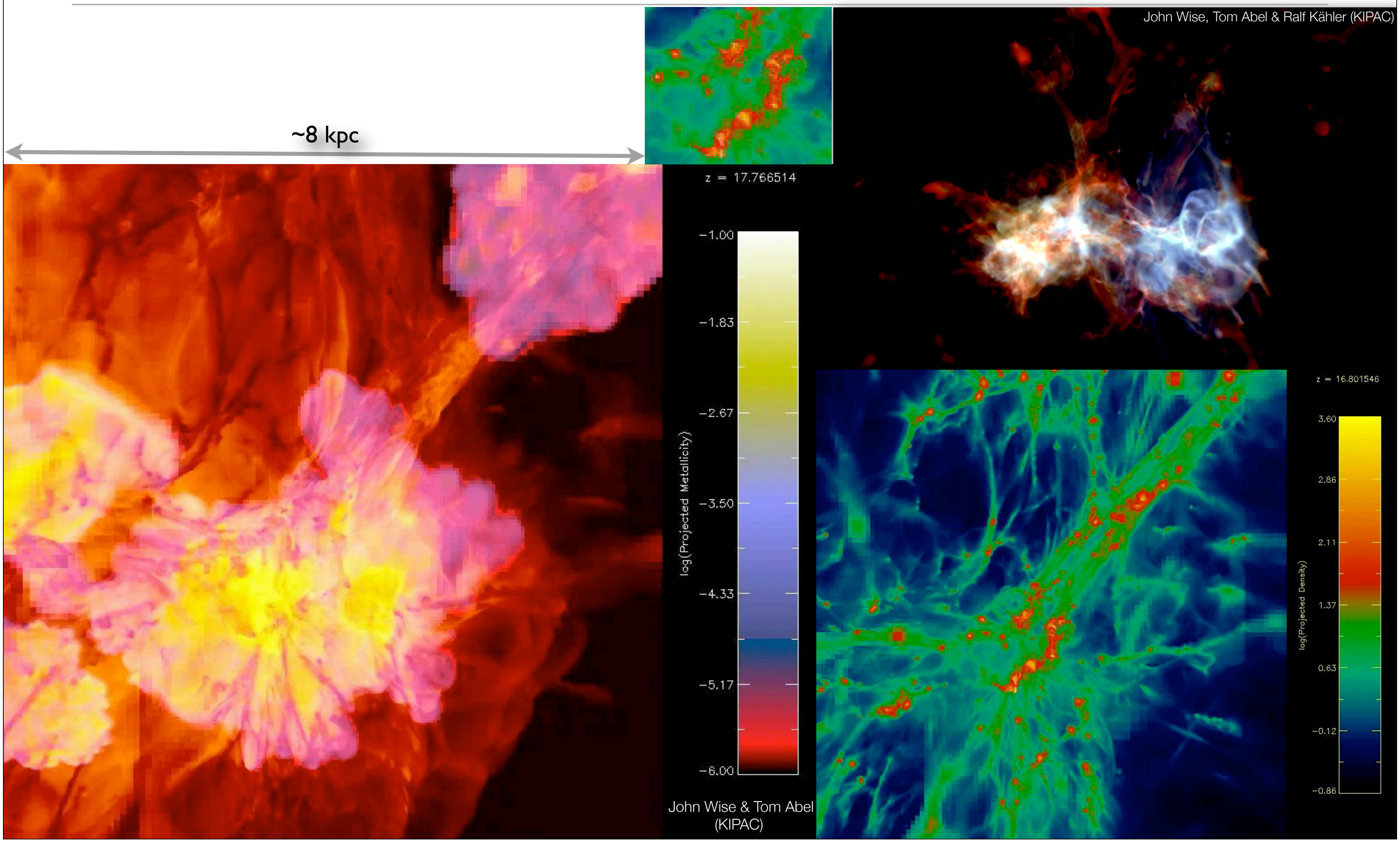


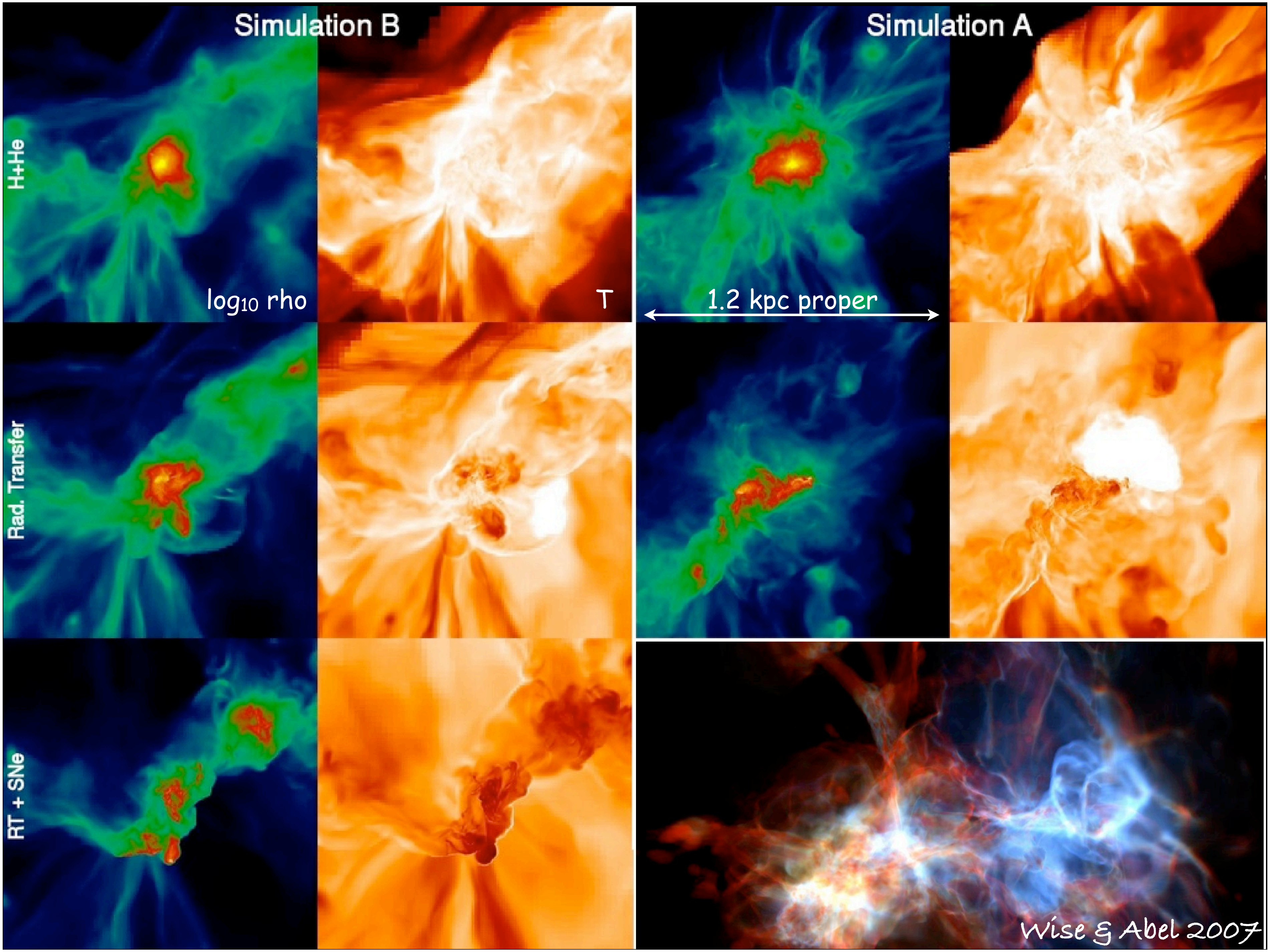


Surprising Life

- No three dimensional stellar evolution calculations but much poorly constrained relevant physics
  - Angular momentum transport
  - Mixing from core, mixing into the atmosphere?
  - Stellar winds, as well as episodic mass loss?
  - Magnetic dynamo? Guaranteed seed field of ~ 4×10^{-10} Gauss from recombination. Larger contribution from Biermann battery.
- Can do:
  - Proto-stars (1st & 2nd generation)
  - HII regions (HeII & HeIII regions)
  - Metal enrichment & potential GRB remnants
  - Beginning of Cosmic Reionization
- Relevant mass range : 1) 30 - 300 solar mass and 2) 10 - 100 solar mass

First few hundred million years





Simulation B
Simulation A
H+He
Rad. Transfer
RT + SNe
log10 rho
T
1.2 kpc proper
Wise & Abel 2007

How big of a difference do Pop III stars make for the first galaxies?

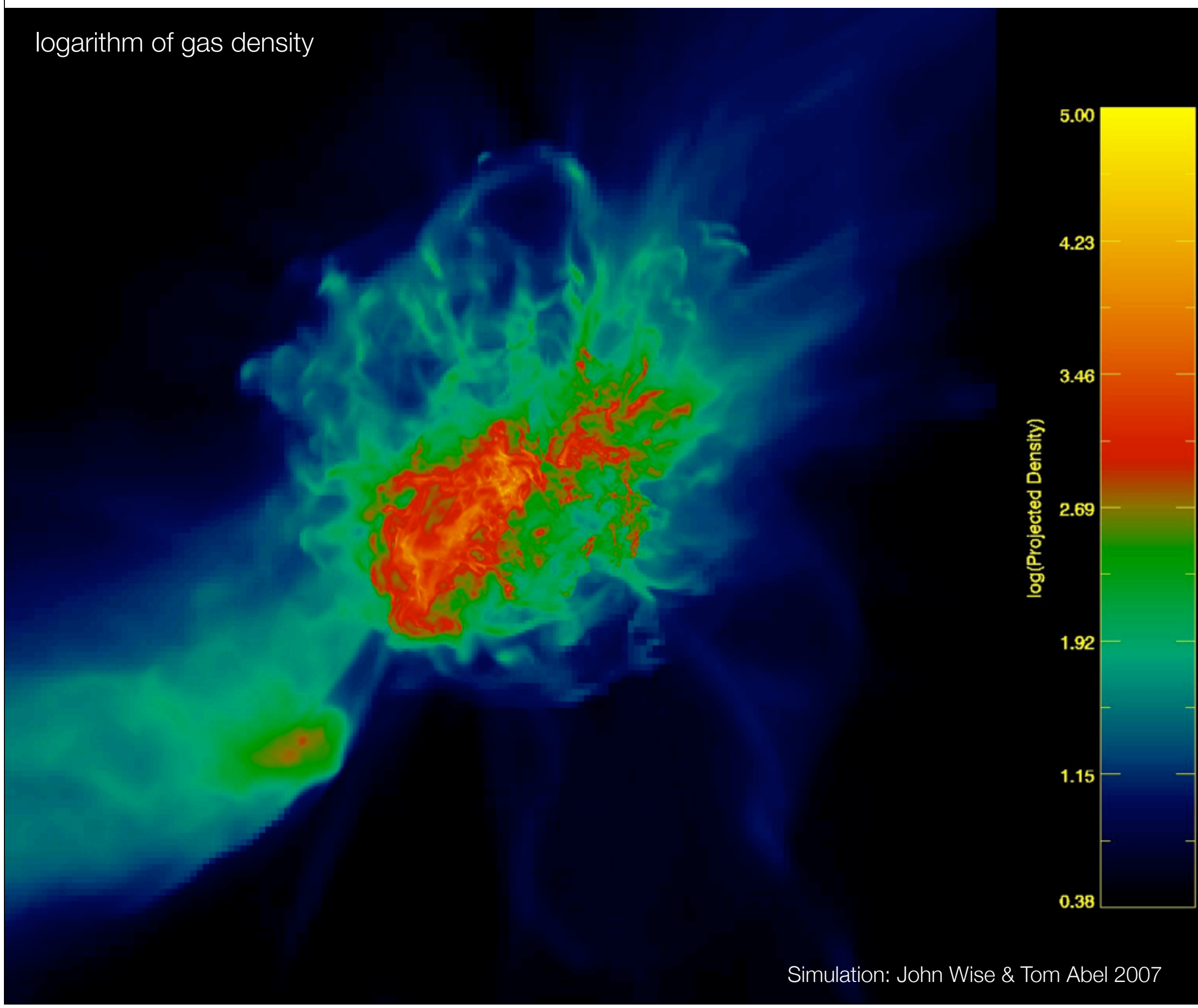
- Feedback is different from an effective equation of state

	Halo Mass [M☉]	Spin Parameter
Simulation A	3.47×10^7	0.030
Simulation B	3.50×10^7	0.022

	N★ (< rvir)	N★ (< 3rvir)	Mgas / Mtot	λgas	
SimA-Std H+He cooling	...	...	0.14	0.010	
SimA-SF transfer only	14	16	[1/2] 0.081	0.053	5
SimB-Std H+He cooling	...	...	0.14	0.010	
SimB-SF transfer only	13	19	[4/5] 0.11	0.022	2
SimB-SNe full	7	13	[1/3] 0.049	0.097	10

Wise & Abel 2007

Making Galaxies one Star at a Time

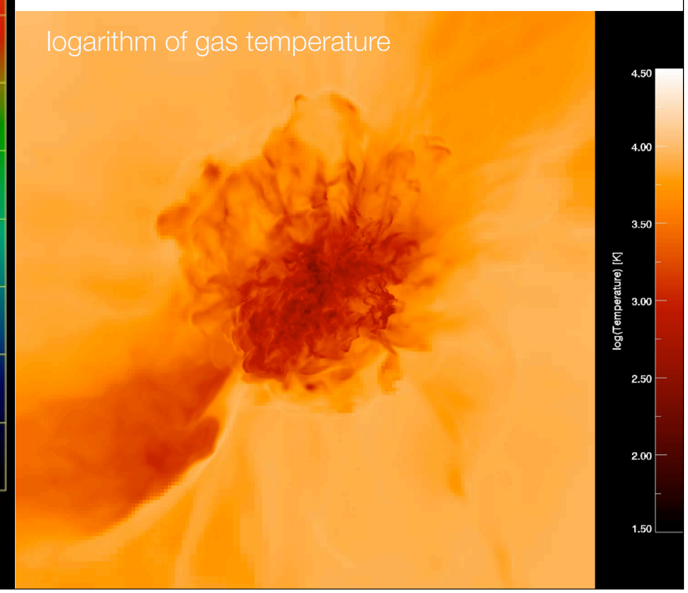


10^8 solar mass galaxy

z~ 20

one star at a time

~ 20 massive stars in progenitor



Summary

- Wide range of birth, life & death of the first massive stars are being explored on super computers
- Second generation primordial stars have lower mass than the first ones.
- HII regions of the first stars evaporate their host-halos leave a medium with ~ 1 cm^{-3} density but can we really assume no winds?
- Enormous impact on subsequent structure formation
    - different angular momentum of gas vs. dark matter
    - turbulence
    - seed the first magnetic fields
    - etc ....

Taking it personal

- Much of you is 13.7 billion years old
- practically nothing of you is younger than 4.5 billion years
- somewhere between 10,000 and ten million massive stars have helped in making you
- about the amount of one of your fingers came from the earliest stars
- you used to be almost a million light years across

Simulation: Brian O'Shea, Mike Norman Visualization: Donna Cox, Stuart Levy, Bob Patterson (NCSA)